HYDROGEN THYRATRONS

New fast-deionizing 4C35 and 5C22 thyratrons permit switching rates up to 5,000 per second for line modulator circuit used in keying magnetrons, for pulsed communication systems, for replacing gaps in spark-type electronic heating units, and for high-speed welding

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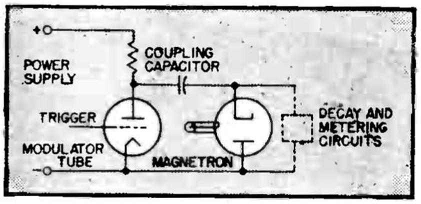


FIG. 1—Simplified circuit of a hard-tube modulator. The low-level trigger pulse is amplified by the modulator tube, normally biased below cutoff and either nonconducting or at voltage saturation to help square up the pulse, then fed to the magnetron through the coupling capacitor

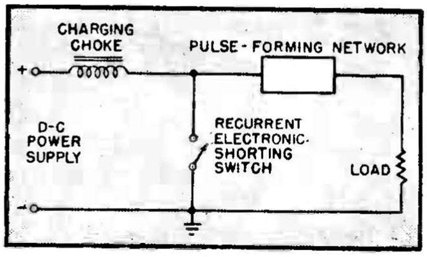


FIG. 2—Simplified circuit of a line modulator. The hydrogen thyratron serves as a shorting switch, closing for the duration of each pulse

AMONG THE MANY new techniques and devices developed as a result of the war effort have appeared hydrogen thyratrons of special design for service in modulators, particularly the pulse modulators of microwave radar systems. In this application these tubes attained a position of considerable importance and by the end of the war were being specified for a majority of the projected radar system designs. The purpose of this paper is to outline briefly the development of two of the most successful of these tubes, their construction and characteristics, and their application to line-type modulators.

It is now well-known that radar utilizes a repetitive series of very short pulses of uhf or microwave radiation to scan the target area. Modulators are used to pulse or key the transmitting oscillators to produce these bursts of r-f power. The briefness of each pulse—with durations of the order of one microsecond—poses special problems in the design of these modulators.

Hard-Tube Modulator

Before the line modulator, particularly as adapted to utilize hydrogen thyratrons, achieved its prominence in radar design, these problems were met by the so-called hard-tube modulator which employed vacuum tubes. In this type of modulator, a basic design of which is shown in Fig. 1, the pulse is formed at low levels to the approximate shape desired and fed to the keyer tube. The resulting amplified and flat-topped high-level pulse is then fed to the magnetron through a capacitor.

Although the hard-tube modulator is capable of producing excellent pulses—indeed, is the only type of modulator which can be used for producing the closely-spaced coded pulses of radar beacon systems—for general search radar it has several disadvantages: (1) The magnetron coupling capacitor is heavy and bulky (since it must have a large value of capacitance to keep the top of the pulse sufficiently flat); (2) The high voltage and current ratings impose harsh requirements on the keyer tubes; (3) Considerable voltage amplification is required to form the low-level trigger pulses.

Line Modulator

The other general type of modulator is the so-called line modulator, to which the hydrogen thyratron is adapted so well. In this type, the pulse is formed directly at high voltage levels as in Fig. 2. A small artificial transmission line, formed of recurrent *LC* networks, charges up between pulses to a very high voltage. Each time the recurrent electronic switch closes, the line releases the stored charge in a surge through the load.

The special design of this line, or pulse-forming network as it is called, is such that this discharge occurs in the desired rectangular pulse shape. The pulse shape and duration are determined entirely by the network;

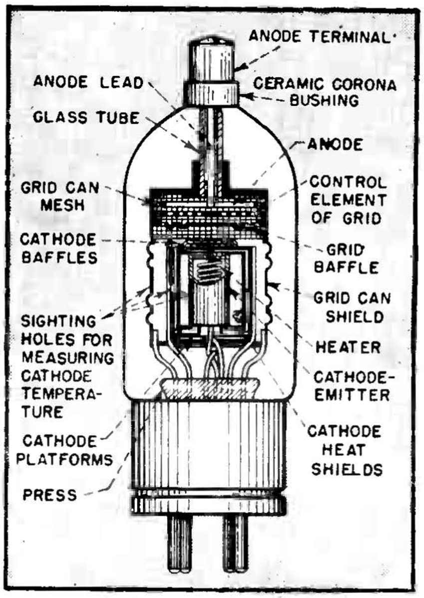
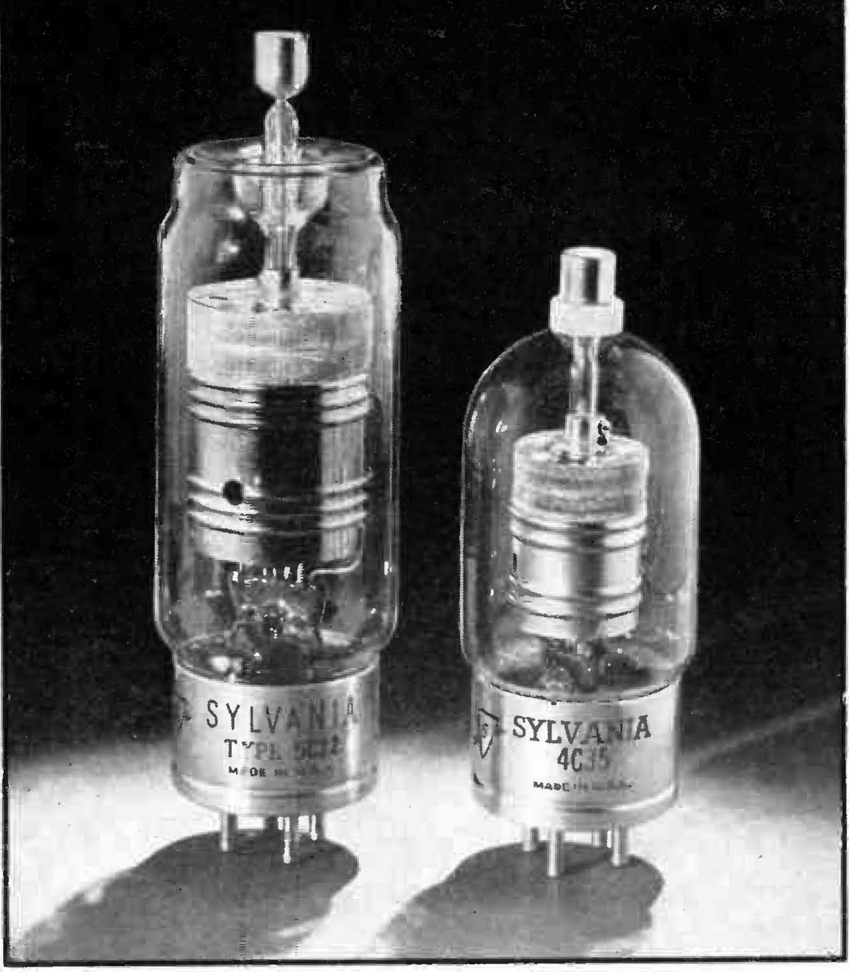


FIG. 3—Construction of type 4C35 hydrogen thyratron



Two typical hydrogen thyratrons

the switch merely initiates the discharge. The switch must close almost instantaneously to achieve a sharp leading edge on the pulse. Although the switch (unlike the keyer tube of a hard-tube modulator) does not have to open as rapidly, since the pulse-forming network controls the pulse behavior once the discharge is started, it must open quickly enough to have no detrimental influence on the charging characteristic or the start of the next pulse.

At the relatively high pulse recurrence frequencies in use (up to 4,000 pps), a rapid deionization time is essential if the switch is to be some sort of gas discharge tube. This type of modulator offers many advantages in regard to simplicity, compactness, and reduction in weight.

Switches for Line Modulators

One of the first switches extensively used in line modulators was the modified rotary spark gap, resuscitated from the early days of wireless. It was noisy and heavy, however, and troublesome as far as life and mechanical maintenance problems were concerned. In addition, it had to be precision-built, and evidenced much time jitter (erratic time variation between successive pulses).

Another form of switch employed was the enclosed fixed spark-gap. These gaps were actually gaseous diodes, being filled with gas at high pressures. Several of these tubes were connected in series to form the switch. Unfortunately, they were characterized by rather low efficiencies owing to their high voltage drops, by excessive trigger requirements, and by restricted voltage operating ranges.

The disadvantages of these early switches led Dr. Germeshausen of MIT Radiation Laboratory to propose in 1942 the use of thyratrons of special design, and to initiate a development program on this project at the Laboratory. Among the advantages which a suitable thyratron would offer were light weight, compactness, ruggedness, simplicity of construction and servicing, stability, flexibility of operation, low tube drop and attendant high efficiency, low grid driving power, low time jitter, and successful operation over a wide range of ambient temperatures (with proper gas fill).

Hydrogen Tube Chosen

The first four advantages are obtained by the choice of a line modulator, but are greatly enhanced by the utilization of a thyratron. Preliminary tests indicated that the above list of advantages could be attained with thyratrons containing hydrogen, and several tube manufacturers were called upon to help complete the development work. The early designs finally crystallized into the type 4C35, later standardized as a JAN type, which operates at peak currents up to 90 amperes with a peak voltage rating of 8 kilovolts.

Shortly after this tube was in production, Sylvania was given a contract to develop a higher-power tube, eventually standardized as the type 5C22. This tube is rated at a peak voltage of 16 kilovolts, and at peak currents up to 325 amperes.

Hydrogen was chosen for the gas fill because of its high ion mobility resulting from its light weight. This factor furnishes the desirable feature of low deionization time, which permits the rapid switching rates that characterize these tubes. Mercury, of course, was automatically ruled out because of its low ion mobility and temperature dependence. In the beginning, helium was also under consideration, for its long mean-free-path would be conducive to high plate voltage ratings. Tubes made with it, however, tended to exhibit cathode deterioration from ion bombardment.

Characteristics of Tubes

The structure of the type 4C35 hydrogen thyratron is illustrated in Fig. 3. The 5C22 is constructed in a similar manner. The anode consists of a circular metal disc fastened to a metal rod, ending in the anode cap at the top of the tube. The grid consists of a cylindrical can which completely surrounds both anode and

Table I — Electrical Ratings of 4C35 and 5C22 Hydrogen Thyratrons

Rating	4C35	5C22
Heater voltage, v	6.3	6.3
Heater current, amp	5.5–6.7	9.6–11.6
Heating time, sec	180	300
Peak anode voltage, kv	8.0	16.0
Peak anode current, amp	90	325
Peak inverse anode voltage, kv*	8.0	16.0
Average anode current, ma	100	200
Pulse duration (measured at 1/2 amplitude), μ sec	6.0	6.0
Pulse repetition frequency, pps**	4,000	
Duty cycle	0.001	0.001
Peak inverse grid voltage, v	200	200
Ambient temperature	− 50 to + 90C	− 50 to + 90C

* In pulsed operation, the peak inverse anode voltage during the first 25 microseconds after the pulse shall not exceed 2.5 kv for the 4C35 or 5 kv for the 5C22.

** The maximum pulse repetition frequency (f_{pr} in pulses per second) will depend on the peak forward anode voltage (e_{py} in volts) according to $(e_{py}^2) \times (f_{pr}) = 2.6 \times 10^{11}$ maximum. Tube may be operated in any position but should be clamped by base only. No cooling stream of air should be directly applied to the tube envelope. Tube should be kept away from strong fields which could ionize gas.

cathode. The latter is a cylindrical structure concentric with the grid can. It consists of an indirectly-heated emitting surface, or cathode proper, surrounded by cylindrical heat shields.

It will be noted that the anode is made closely-spaced from the grid. The spacing is considerably less than the mean-free-path of the hydrogen at the operating temperature. This feature is responsible for the high operating and hold-off voltages. Particular attention was given to the detailed design of the anode seal, since combined temperature and voltage effects could cause cracks in the seal. This would permit a discharge directly from the anode to the grid structure, with consequent loss of control of the tube.

The actual control element of the grid structure is the perforated disc below the anode. A baffle is mounted beneath this disc. For the final design an equipotential cathode with radiation baffles was adopted in order to avoid the difficulty with hot spots which occurred in the original directly-heated cathodes. A considerable increase in heating time results with this type of cathode, but many advantages accrue which overbalance the slight disadvantage of a longer heating time.

The mechanism of firing seems to be as follows: When the trigger pulse is applied, grid current begins to flow as a trigger voltage builds up. When this current has reached the required value, a plasma is established in the grid-cathode region. The electric field from the anode, being so intense, then causes a diffusion of electrons over to the grid-anode region. Almost immediately a plasma is established in this region, followed by an arc from anode to cathode.

A summary of the ratings on the type 4C35 and 5C22 hydrogen thyratrons is given in Table I. Recent tests indicate a life of nearly 2,000 hours for these tubes, and research now under way on cathode techniques may result in even better life figures. The 5C22 has been operated at repetition rates of 1,000 to 5,000 per second using 8 kilovolts and 75 amperes peak current, and the 4C35 has operated at frequencies over 100,000 cps at fairly low voltages and currents. For comparison, radar systems employ pulse recurrence frequencies from 100 to 4,000 pulses per second, pulse widths from 0.1 to 6.0 microseconds, peak thyratron anode voltages from 1 to 30 kilovolts, and peak powers from 5 to 3,000 kilowatts.

Hydrogen Thyratron Circuit

A practical circuit utilizing a hydrogen thyratron is shown in Fig. 4. The load in this case happens to be a pulse transformer and magnetron oscillator. The step-up pulse transformer permits magnetrons to be operated at higher voltages than the maximum thyratron voltage ratings, a fact that is aided by the high peak current capabilities of the tubes, and matches the magnetron impedance to that of the pulse-forming network. The pulse cable permits the oscillator to be located in a position remote from the modulator.

Since the anode of most magnetrons must be integrally connected to the coaxial or waveguide output transmission line, for safety reasons the anode is maintained at ground potential. This would require a filament transformer insulated for full peak voltage. By utilizing a pulse transformer with a bifilar secondary winding, a magnetron filament transformer with low insulation requirements can be used.

The pulse-forming network consists of a series of small *LC* sections connected in tandem to form a recurrent-network artificial transmission line open-circuited at the far end. Although many networks may be used to produce a wide variety of pulse shapes, for radar purposes from three to seven similar sections are generally used. This network charges up between pulses when the thyratron is off, and discharges in a rectangular pulse when it fires.

Network Discharging Action

If the network is charged to a voltage E, the short-circuit set up by the firing of the thyratron suddenly causes the voltage across the network terminals to drop from E to $+E/2$ and causes a voltage $-E/2$ to appear across the load. This sudden voltage change at the network terminals surges down the transmission line, is reversed and reflected at the end, and travels back to neutralize the voltage at the network terminals, as shown in the voltage profile along the pulse-

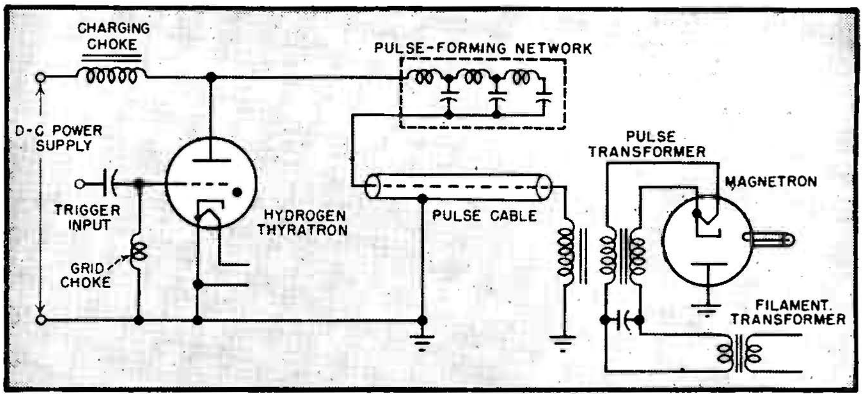


FIG. 4—Practical line modulator circuit employing a hydrogen thyratron to drive a magnetron oscillator

forming network at various instants of time (Fig. 5A). The terminal voltage stays at $E/2$ while the voltage surge is traveling along the line, as in Fig. 5B. Thus, there is produced the rectangular current pulse of Fig. 5C, with a duration depending on the length of time it takes the surge to travel down the line and back. By varying the number of sections or by changing the values of L and C in a manner consistent with other requirements, the pulse width may be varied as desired.

The cancellation of voltage at the terminals when the surge returns is perfect if the load impedance is equal to the characteristic impedance of the line. If the match is not perfect, there will be multiple reflections and re-reflections in the line until the surge energy has been completely dissipated. The load voltages for such cases are shown in Fig. 5D and 5E.

Network Charging Action

For the charging phase of the operation of the line modulator, the network inductances are so small compared to the charging choke, which is measured in henrys, that we may neglect them. The equivalent circuit is then as in Fig. 6A. In such a circuit, if we open switch S (no initial inductance current), the voltage across the switch will follow the well-known behavior of Fig. 6B.

In the so-called resonance charging, the inductance is chosen to resonate with the network capacitance at a frequency one-half that of the pulse recurrence frequency in use. The voltage waveform across the thyratron or switch S is then as in Fig. 6C, a repetition of the portion AB of the transient in Fig. 6B. This portion is essentially one-half a period of a sine wave.

In the so-called linear charging, the inductance is greater than that required for resonance at the frequency in use, and the thyratron voltage waveform approaches the saw-tooth pattern of Fig. 6D as the inductance is increased.

A third method of charging, the so-called diode charging, utilizes a small hold-off diode in conjunction with an inductance less than that required for charging at the frequency in use, as in Fig. 6E. The diode keeps the voltage from dropping off after the peak has been reached, giving the output voltage waveform of Fig. 6F.

Design of Charging Choke

Since in practice a modulator is frequently designed to operate at several combinations of pulse repetition frequencies and pulse lengths, a common arrangement is to employ a choke which is resonant at the lowest repetition frequency desired. This will then provide linear charging at the higher frequencies. The current through the charging choke periodically reaches zero with resonance and diode charging, but does not with linear charging, where constant current is approached. It should be pointed out that the current passing through chokes for resonant and diode charging has very high a-c components, so that these chokes differ markedly in design from the usual filter chokes, which are designed for currents having small a-c components superimposed on a large direct current.

Because of the electrical inertia of the inductance, the thyratron anode voltage swings up above the power supply voltage in the periodic transients described. The peak voltage reached by the thyratron is approximately twice that of the power supply voltage. The actual voltage across the load (into the pulse transformer, if employed) is about one-half that of the network peak voltage, and about equal to that of the supply.

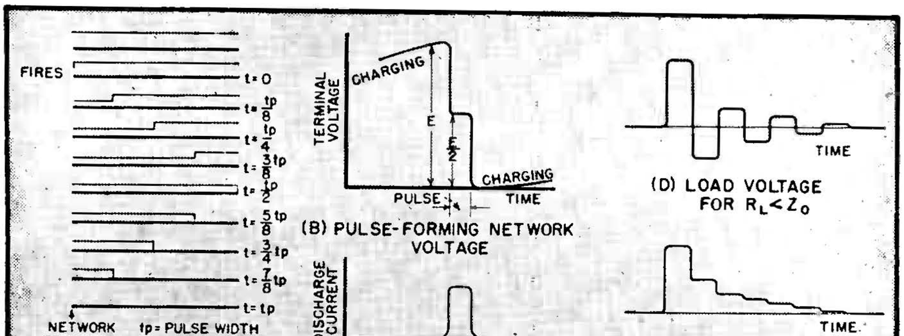


FIG. 5—Voltage and current waveforms in a line modulator circuit

Magnetron Sparking

The information in Table II may be of help in designing a radar line modulator using a hydrogen thyratron to drive a magnetron. When the magnetron oscillator is employed as the modulator load, the phenomenon of magnetron sparking must be carefully considered. This sparking consists of intermittent transient gaseous discharges due to gas liberated in the tube from such sources as the cathode or by field emission from the metal parts. Most magnetrons spark when first operated after an appreciable time of inoperation. This type of sparking usually cleans up after the first few minutes of operation. In the case of high-powered magnetrons, it occurs throughout life and, if the sparking rate is not excessive, does not cause any harm in the system performance.

When a magnetron sparks, the impedance match of the network and load is destroyed, since the magnetron is practically a short circuit. The network is left with a negative charge, so that, depending on the degree of mismatch, the succeeding pulse can recharge the network to 3 or 4 times the normal peak thyratron voltage. Thus, with high-power magnetrons, and particularly with long pulse widths (where the network capacitance energy storage is high), the modulator circuit components must be protected. This protection is usually provided by a shunt diode connected across the network or across the thyratron, as in Fig. 7A and 7B. With a suitable diode, the inverse voltage developed across the network is rapidly discharged and the peak network voltage held substantially constant on the succeeding recharge cycle.

Deionization Time

At high repetition rates at or near maximum peak currents, consideration must be given to the deionization time when the tube shuts off. If the anode voltage increases too rapidly, the cathode-grid region may not be sufficiently deionized before the anode voltage attains a value capable of reigniting the discharge. Under extreme conditions, the tube may fire itself at a rate sufficiently high to overload the average current capabilities of the power supply and kick out the overload relay. Without any additional techniques, resonance charging would be the preferred type of charging where rapid deionization is a factor, because its waveform is such as to keep the anode voltage low immediately after the pulse.

Where deionization must be considered, however, it is customary to introduce deliberately a slight mismatch to the network to provide an inverse anode voltage. By the time that the anode voltage has then reached the level where it might reignite the discharge, deionization is sufficiently complete to prevent reignition. The inverse voltage may also be produced by inserting an inductance of the order of a few microhenrys in the anode lead of the thyratron. The use of a negative grid bias, by sweeping out the positive ions remaining in the cathode-grid space immediately after a pulse (either alone or together with the aid of inverse voltage), is advantageous at high repetition rates.

Trigger Voltage Requirements

Although most tubes will fire with trigger voltage amplitudes and durations considerably lower than the minimum specified, the specifications were set conservatively to insure satisfactory triggering under all conditions. The specified JAN trigger is shown in Fig. 8. Practically all tubes will fire with a 100-volt, 2-microsecond trigger. Some tubes, however, require a trigger with a moderate amplitude and length for initial starting; after firing, the trigger can be reduced to 50 volts amplitude with satisfactory operation on most tubes.

With the specified trigger the time delay will vary from 0.5 to 0.9 microsecond for all tubes on both the 4C35 and the 5C22. Time delay here is the time from the start of the trigger pulse to the firing of the anode. It will vary greatly with changes in trigger voltage amplitude and rate of rise, whereas it is only slightly affected by changes in anode voltage or trigger output impedance. Where time delay is important, it is then possible by using a stiffer trigger pulse to reduce both the time delay and the spread in time delay from tube to tube.

As an example, a trigger with an amplitude of 200 volts, a rate of rise of 800 volts per microsecond, and an output impedance condition of 500 ohms will reduce the time delay to 0.2 to 0.6 microsecond. This stiffer trigger will also reduce the time jitter (variation of time delay from pulse to pulse for a single tube under given conditions). The maximum time jitter with the minimum specified trigger is 0.04 microsecond, a value that will be reduced to about one-half as much with the recommended stiffer trigger.

It has been found that using d-c power on the heater will reduce the jitter to a negligible amount regardless of the trigger pulse shape. This indicates that the jitter is caused by the effect of the magnetic field of the heater coil on the grid current. The time jitter in these tubes is so low as to be negligible for ordinary purposes, but it seems likely that a reverse coil type of heater, in which the magnetic field is greatly neutralized, would provide a jitter-free tube for an a-c filament source if desired. A comparison of a trigger pulse shape meeting specifications and one recommended for minimizing time delay and jitter is shown in Fig. 8.

A capacitance is usually employed for feeding the trigger to the grid, with a resistance or inductance as the grid-leak impedance element. Under certain conditions, the anode voltage may cause the grid to become positive during some part of the charging cycle, through the coupling of the anode and grid circuits by the grid-anode tube capacitance. Premature firing could occur. For this reason, when a resistance is used it should not exceed 20,000 ohms, and the coupling capacitor should not be less than 0.05 microfarad. It is generally desirable to use an inductance since this will prevent the grid voltage from rising during the charging cycle. A value of 5 to 25 millihenrys will be found satisfactory. An inductance is particularly preferable when grid bias is used to aid deionization, and it should be kept as low as possible consistent with maintaining the trigger pulse shape dictated by the minimum specifications or by time delay considerations.

Trigger Generator Circuit

A simple and compact two-tube trigger generator designed by R. Fricks which meets all the requirements of the trigger specifications is presented in Fig. 9. It was developed for a short-range navigational radar set and has proven to be quite stable during power supply variations. Frequency control may be obtained by

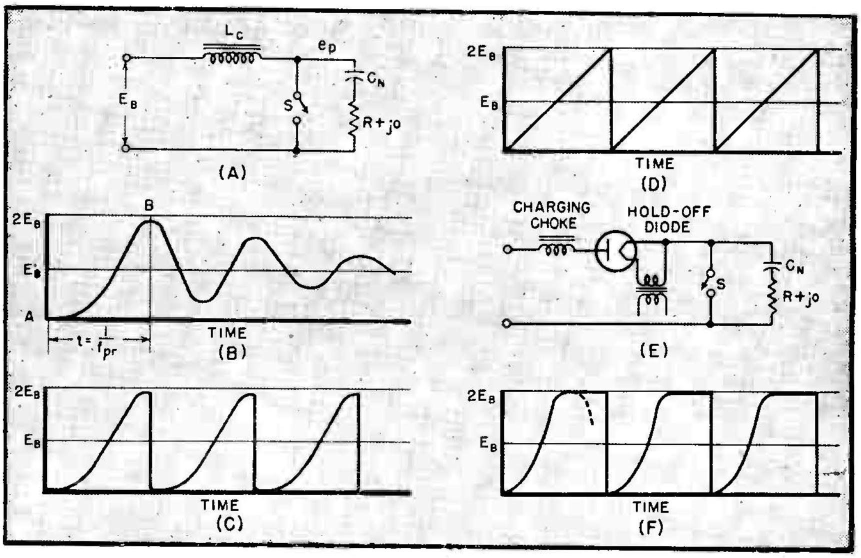
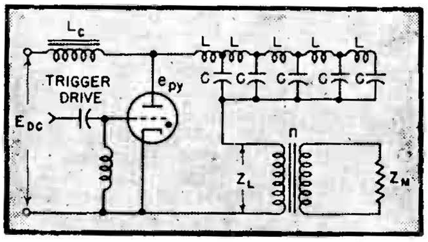


FIG. 6—Equivalent circuit of line modulator in charging phase (A), voltage waveform across switch after closing (B), resonance charging voltage waveform across thyratron (C), linear charging voltage waveform across thyratron (D), circuit for diode charging (E), and diode charging voltage waveform across thyratron (F)

Table II—Line Modulator Design



f_{pr}	Pulse repetition rate
t_p	Pulse width
e_{py}	Peak thyratron forward anode voltage
e_{px}	Peak thyratron inverse anode voltage
I	Average thyratron anode current
i_b	Peak thyratron anode current
I_M	Average oscillator anode current
i_M	Peak oscillator anode current
C	Network section capacitance
N	Number of network sections
C_N	Total network capacitance
L	Network section inductance
P_p	Peak load power
P_A	Average load power
Z_L	Transformed load impedance
Z_M	Oscillator impedance
Z_N	Network characteristic impedance
e_m	Oscillator efficiency
E_L	Peak load voltage
E_M	Peak oscillator voltage
P_{op}	Oscillator peak r-f power
P_{oa}	Oscillator average r-f power
$E_{d\text{-}c}$	D-C power supply voltage
L_C	Charging choke inductance
n	Pulse transformer turns ratio

$$Z_N = (L/C)^{1/2}$$

$$t_p = 2\,N\,(LC)^{1/2}$$

$$i_b = \frac{e_{py}}{Z_N + Z_L} = \frac{e_{py}}{2Z_L} \text{ for load matched to network}$$

$$P_p = \left(\frac{e_{py}}{Z_N + Z_L}\right)^2 Z_L = \frac{e_{py}^2}{4Z_L} \text{ for load matched to network}$$

$$P_A = \frac{e_{py}^2}{4Z_L} f_{pr}\, t_p \text{ for match}$$

$$P_{op} = P_p e_m \qquad I = i_b f_{pr}\, t_p$$

$$P_{oa} = P_A\, e_m$$

$$E_L = \frac{e_{py}}{Z_N + Z_L} Z_L = \frac{e_{py}}{2} \text{ for load matched to network}$$

$$E_M = n^2 E_L$$

$$n^2 i_M = i_b$$

$$e_{py} \cong 2\,E_{d\text{-}c}$$

$$f_{pr} = \frac{1}{\pi\,(L_C\,C_N)^{1/2}} \text{ for resonance charging}$$

$$L_C > \frac{1}{\pi^2 f_{pr}^2\, C_N} \text{ for linear charging}$$

varying the time constants of the multivibrator coupling circuits.

During the establishment of a plasma in the grid-anode region when the tube starts to fire, the grid potential is raised to a very high voltage for a few hundredths of a microsecond. The so-called grid spike of Fig. 10A results. It does not have much energy, but can radiate noise and also interfere with the operation of certain types of trigger circuits.

In some cases, it may be desirable to attenuate the action of the spike voltage on the trigger circuit. A low-pass filter can be readily designed to pass the grid voltage into the thyratron to prevent the spike from getting back into the generator. When such a filter is used, components rated at high voltage should be specified because of the high transient voltages involved. A t-r gas switching tube can also be used, although a gas diode with an ignition potential of the order of 300 to 400 volts may be connected across the thyratron grid and cathode. Typical grid potential curves appear in Fig. 10A and 10B.

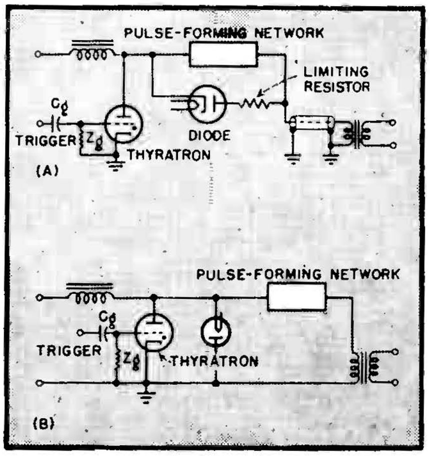


FIG. 7—Two circuits for protecting a line modulator against magnetron sparking

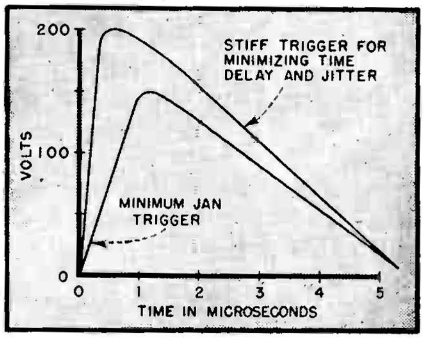


FIG. 8—Recommended open-circuit trigger voltage shapes

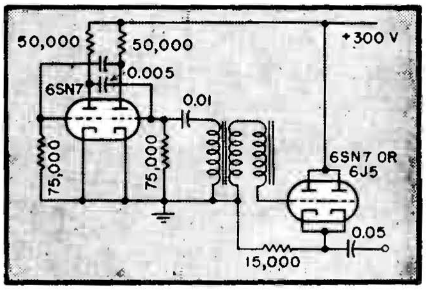


FIG. 9—Compact trigger generator circuit recommended for use with 4C35 and 5C22 hydrogen thyratrons

Tube Life

During the early period of the development of the 4C35, the life was found to decrease markedly with increase in the rate of rise of the anode current. It was found that this could be overcome by improved processing techniques, and it was then thought that no limit on the rate of rise of anode current was required. Subsequently, it became apparent on the 5C22, however, that the rate of rise was important in connection with tube dissipation.

During the ionizing time of the tube, the anode potential is decreasing at an extremely rapid yet finite rate. If the anode current is permitted to rise at a high rate during this time, then the tube dissipation will be increased. It has been confirmed that, at a constant duty cycle (pulse recurrence frequency multiplied by pulse width), the average dissipation is almost a linear function of the repetition rate; this is the reason for the maximum rating of $e_{py}^2 \times f_{pr}$.

In many cases, the ceiling on the rate of rise may be set by the requirement of satisfactory operation of the oscillator, but in any event it is wise to limit it to a value consistent with satisfactory overall system performance. At low repetition rates, the tube dissipation will be low and, since a portion of the dissipation causes cathode heating, the pulse cathode temperature may be lower than normal. Under these conditions (particularly at high peak currents), a fast rate of rise may result in cathode sparking in the thyratron. This condition can be considerably aggravated by the stray capacitance to ground of any of the circuit components connected to the anode. This capacitance is charged to full peak anode voltage. When the tube fires, this stray capacitance may discharge through the thyratron and not through the network load circuit. The resultant spike on the leading edge of the pulse causes the sparking. An inductance of a few microhenrys in the anode lead will be useful in limiting the rate of rise, and will not seriously distort the pulse unless it is extremely short.

The heating time of the 4C35 and 5C22 are three and five minutes, respectively, but the heating time may be reduced by increasing the applied heater voltage during the warm-up period. After the heating period the full anode voltage may be applied abruptly.

Frequency Considerations

Because of the pulsing of the magnetron, it does not furnish r-f power output at a single frequency, but over a continuous spread of frequencies closely spaced about a center value as shown in Fig. 11. If this spread is too great, much of the r-f output energy radiated may be useless, because the narrow bandwidth of the receiver limits the frequencies it can detect.

One factor which can contribute to such excessive broadening of the spectrum is a poor voltage pulse shape applied to the magnetron. This results in both frequency and amplitude modulation. The high pushing figures (instantaneous rates of change of radio frequency with respect to magnetron plate current) of some magnetrons place stringent requirements on how uniform and constant the top of the voltage pulse should be throughout the duration of the pulse. Although the static magnetron impedance is about 1,000 ohms, the low dynamic impedance (50 to 100 ohms in some cases) emphasizes any variation in this voltage, as illustrated in Fig. 12, and greatly deteriorated spectra result.

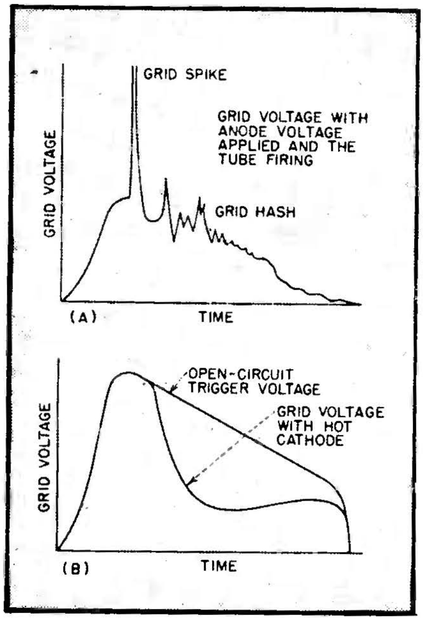


FIG. 10—Typical grid potential waveforms in trigger generator circuit

Hydrogen thyratrons may be operated successfully in parallel and series to increase the peak network voltage or peak current.

Industrial Applications

In addition to the radar applications for which the hydrogen thyratron was originally designed, there are many places where the light weight, simplicity, flexibility and ease of operation, high voltage and current capabilities, and the rapid switching performance of tubes of this type will be of value. In pulsed communication systems, in microwave local heating of glass or plastic, and in dielectric heating it has excellent possibilities. The replacement of rotary spark gaps in radar by thyratrons logically suggests the adaptation of these tubes to spark-gap induction heaters. A small 500-watt induction heater using a single thyratron has been constructed. It gave high efficiency, with an output readily controlled by adjusting the drive frequency. This suggests possible special applications for diathermy and electrosurgical equipment.

The accurately spaced pulses obtained by using pulse techniques suggest use in high-speed welding. The fact that the tube is off between pulses would permit recovery time to avoid depolarization effects in electroplating in a properly-designed system.

The rapid deionization time lends itself to employment in high-speed oscilloscope sweep circuits and to servomechanisms and motor controls where rapid switching is a factor of importance.

In a light-modulator circuit with a pulser similar to that described, a hydrogen thyratron was used to flash a gas discharge tube at frequencies between 5,000 and 6,000 times per second. Intense short-duration light flashes obtained in this way can be utilized with a uniform film motion for study of high-speed motion.

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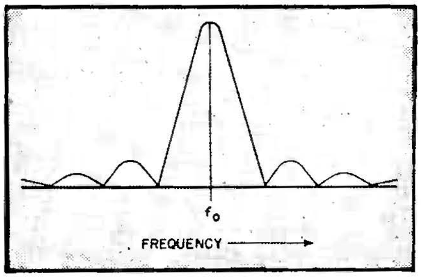

FIG. 11—Radio-frequency output spectrum of an oscillator pulsed by a rectangular pulse, as computed by Fourier analysis. At 10,000 mc the spread of the central lobe is of the order of a few megacycles

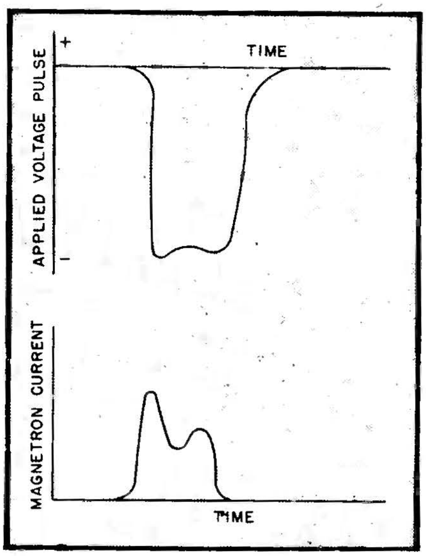

FIG. 12—Effect of a poor voltage pulse on magnetron current pulse shape, showing how a slight irregularity in the bottom of a voltage pulse is magnified in the current pulse

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